Orion Entry Display Feeder and Interactions with the Entry Monitor System

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The Orion spacecraft is designed to return astronauts to a landing within 10 km of the intended landing target from low Earth orbit, lunar direct-entry, and lunar skip-entry trajectories. While the landing is nominally controlled autonomously, the crew can fly precision entries manually in the event of an anomaly. The onboard entry displays will be used by the crew to monitor and manually fly the entry, descent, and landing, while the Entry Monitor System (EMS) will be used to monitor the health and status of the onboard guidance and the trajectory. The entry displays are driven by the entry display feeder, part of the Entry Monitor System (EMS). The entry re-targeting module, also part of the EMS, provides all the data required to generate the capability footprint of the vehicle at any point in the trajectory, which is shown on the Primary Flight Display (PFD). It also provides caution and warning data and recommends the safest possible re-designated landing site when the nominal landing site is no longer within the capability of the vehicle. The PFD and the EMS allow the crew to manually fly an entry trajectory profile from entry interface until parachute deploy having the flexibility to manually steer the vehicle to a selected landing site that best satisfies the priorities of the crew. The entry display feeder provides data from the EMS and other components of the GNC flight software to the displays at the proper rate and in the proper units. It also performs calculations that are specific to the entry displays and which are not made in any other component of the flight software. In some instances, it performs calculations identical to those performed by the onboard primary guidance algorithm to protect against a guidance system failure. These functions and the interactions between the entry display feeder and the other components of the EMS are described.

Attitude Indicators

The PFD is shown in Figure 1. The PFD can be broken up into 3 main areas. The first area, shown in the blue outline, consists of spacecraft attitude indicators, attitude errors, bank angle queues. The Attitude Director Indicator (ADI) ball provides a 3D representation of the spacecraft attitude in a Local Vertical Local Horizontal (LVLH) reference frame. These attitudes are provided as Euler angles, which are converted within the entry display feeder, from a direction cosine matrix using a pitch, yaw, roll Euler sequence. The corresponding attitude rates and errors are shown on the graduated bar scale on the top, right, and bottom of the ADI ball. During entry, the crew can manually control the bank angle but not the pitch and yaw angles. Pitch and yaw forces are dominated by aerodynamics effects and cannot be significantly affected by thrusters during entry, so those channels are disabled. The current bank angle is displayed with the magenta airplane symbol, while the commanded bank angle is displayed with the green airplane symbol. The commanded bank angle is smoothed with a low-pass filter with a time constant of 0.2 seconds to prevent jumpiness that would distract a crew. The vertical, magenta needle shows the bank angle error, and the entry display feeder calculates the direction of the

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needle consistent with the shortest time and least fuel consumption while operating independently of any guidance and control algorithms. To fly a precision entry the crew must have a means to anticipate the time to the next bank reversal, which is shown along with a digital readout of the current delta-azimuth on the digital display below the ADI ball. This estimate is based on the current lateral angle, current lateral angle rate, and lateral angle deadband. A bank reversal is triggered when the lateral angle exceeds the lateral angle deadband and is consistent with the primary entry guidance algorithm, PredGuid. These attitude indicators provide the crew with the visual queues to modulate bank in a manner consistent with PredGuid while flying manually. As currently designed, the backup guidance algorithm, Loads Managed Guidance (LMG), does not execute bank reversals, so this display is disabled when LMG is active.

Entry Footprint Display

The second area of the PFD consists of the entry footprint and bank angle displays, shown in the red outline on Figure 1. The current lift direction, consistent with the current bank angle, is shown with an arrow on the dial display. The entry footprint display provides the crew with geographic situational awareness during entry. Because the crew is flying backwards through the atmosphere, the footprint is oriented upside down (South is on the top and North is on the bottom) such that the California coastline is shown on the bottom of the display. This display orientation provides the crew with consistency between the bank commands and the predicted landing site. Throughout entry, the entry re-targeting module calculates all of the onboard trajectory propagations and passes the data to the footprint display via the entry display feeder. The target landing site is indicated by the circle labeled "SNC" (San Clemente Island), and the predicted landing site assuming a current, constant bank angle is indicated by the parachute. The predicted landing site of the backup guidance algorithm, Loads-Managed Guidance (LMG) is indicated by the "L," and the ballistic landing site is indicated by the "B." The capability footprint is indicated by the closed polygon, which shows the predicted landing sites at constant bank angles of 0° (full lift up), ±30°, ±60°, ±90°, and 180° (full lift down). To the right of the footprint are the bank angles, and the corresponding maximum G-loads that would be encountered when flying these constant-bank trajectories to parachute deploy. When the target landing site falls outside of the capability footprint due to a spacecraft fault or trajectory error, the onboard re-targeting module of the EMS recommends a new landing site to the crew via an alert in the yellow area of the footprint display. It also recommends the safest reachable re-targeted landing site based on a pre-loaded list of contingency areas. If none of those sites are available, the re-targeted landing site is recommended based on a pre-loaded relative factor of safety matrix that underlies the entry footprint display. The footprint display provides the crew with the visual queues to manually fly to the safest possible landing site within the capability of the vehicle.

Additional Flight Control Indicators

The third area of the PFD consists of basic flight control indicators, excluding attitude indicators. These data are passed directly from the absolute navigation domain of the GNC flight software to the displays via the entry display feeder and are shown in the orange outlines on Figure 1. The dial displays show altitude, altitude rate, and current acceleration (G-load). The yellow and red G-load limits of 10gs and 12gs, respectively, are also on the acceleration indicator. Earth-relative velocity is shown on a tape display to the left of the ADI ball. These basic flight control indicators complement the other displays on the PFD

and provide the pilots with additional situational awareness necessary to fly an entry manually.

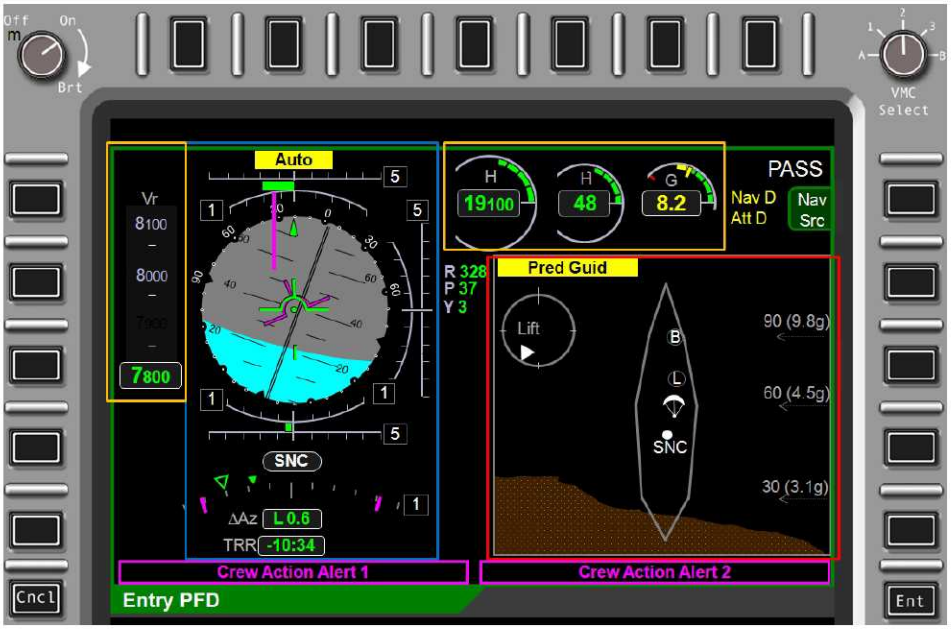

Figure 1: Entry Primary Flight Display